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TECHNICAL REPORT NO. 67-16

LONG-PERIOD SEISMOGRAPH DEVELOPMENT

Quarterly Report No. 3, Project VT/6706

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GEOTECH

A TELEDYNE COMPANY

TECHNICAL REPORT NO. 67-16

LONG-PERIOD SEISMOGRAPH DEVELOPMENT

Quarterly Report No. 3, Project VT/6706

by
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Sponsored by

Advanced Research Projects Agency
Nuclear Test Detection Office
ARPA Order No. 624

GEOTECH
A TELEDYNE COMPANY
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Garland, Texas

15 April 1967

IDENTIFICATION

AFTAC Project No:	VELA T/6706
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Name of Contractor:	Teledyne Industries, Geotech Division Garland, Texas
Contract No:	AF 33(657)-16406
Effective Date of Contract:	15 June 1966
Amount of Contract:	$172,800
Project Manager:	Richard M. Shappee BR1-2561, Area Code 214

CONTENTS

ILLUSTRATIONS

ABSTRACT

The first module of a long-period triaxial borehole seismometer was assembled. Preliminary tests were conducted to determine its operating characteristics. An undesirable mass position versus temperature characteristic was observed. Probable causes have been determined and will be corrected.

LONG-PERIOD SEISMOGRAPH DEVELOPMENT

1. INTRODUCTION

This report discusses the development of a long-period triaxial borehole seismometer, the system in which it will operate, and the design concepts, of the uphole control apparatus.

The purpose of this report is to present the technical accomplishments of this project for the period from 1 January 1967 through 31 March 1967. It is submitted in compliance with paragraph 2, Data Requirements, of the Statement of Work to be Done, AFTAC Project Authorization, No. VELA T/6706 dated 11 March 1966. The project is under the technical direction of the Air Force Technical Applications Center (AFTAC) and under the overall direction of the Advanced Research Projects Agency (ARPA).

2. DEVELOPMENT OF A LONG-PERIOD TRIAXIAL BOREHOLE SEISMOMETER, TASK 1b

2.1 INTRODUCTION

Since the last quarterly report we have assembled the first module of the seismometer. The design concepts were discussed in the previous quarterly reports.

2.2 STATUS OF WORK

2.2.1 Seismometer

Tests of the first seismometer module have been started. Figure 1 shows one module of the seismometer. Figure 2 shows a plot of free period as a function of mass position. Adjustments were made in the length of the main suspension spring to minimize the change of free period. Figure 3 shows the effect of changes in orientation of the triflexure. The variation in period with mass position is similar to that found in the Geotech Model 7505 long-period vertical seismometer.

Figure 4 shows the tilt sensor which furnishes the vertical reference for the tilt table motors in both the cross and the sensitive axes. The sensor is mounted between the side frames of the sensitive element and below the helical spring. This position places it approximately at the center-of-rotation of the tilt table.

Four precision mercury switches are used in the tilt sensor. The maximum measured sensitivity of these switches was found to be 7 minutes of arc. To avoid electrical damage to the switches, simultaneous closure of the two

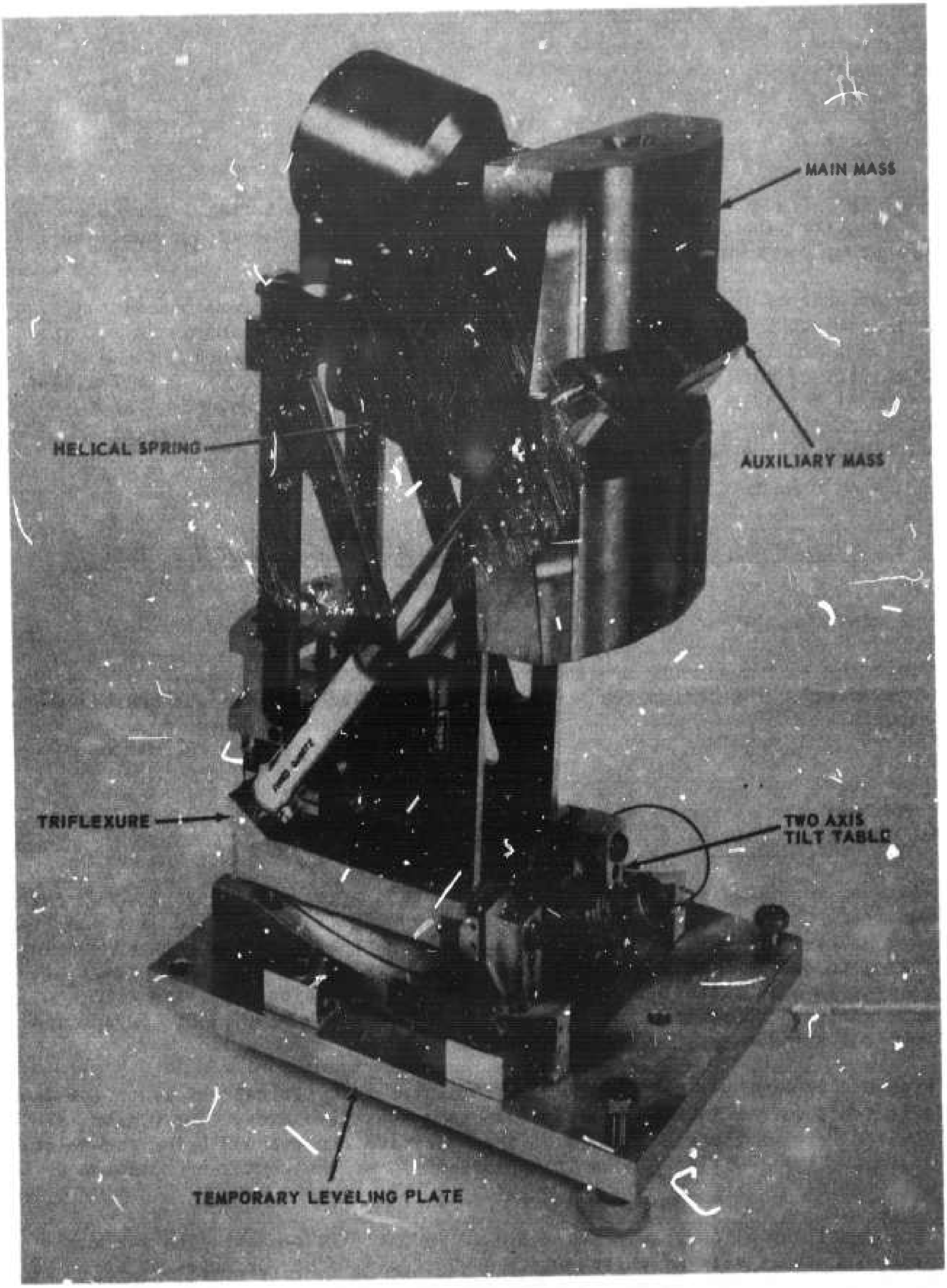

Figure 1. Sensitive element, Model 26310 long-period triaxial borehole seismometer

G 2197

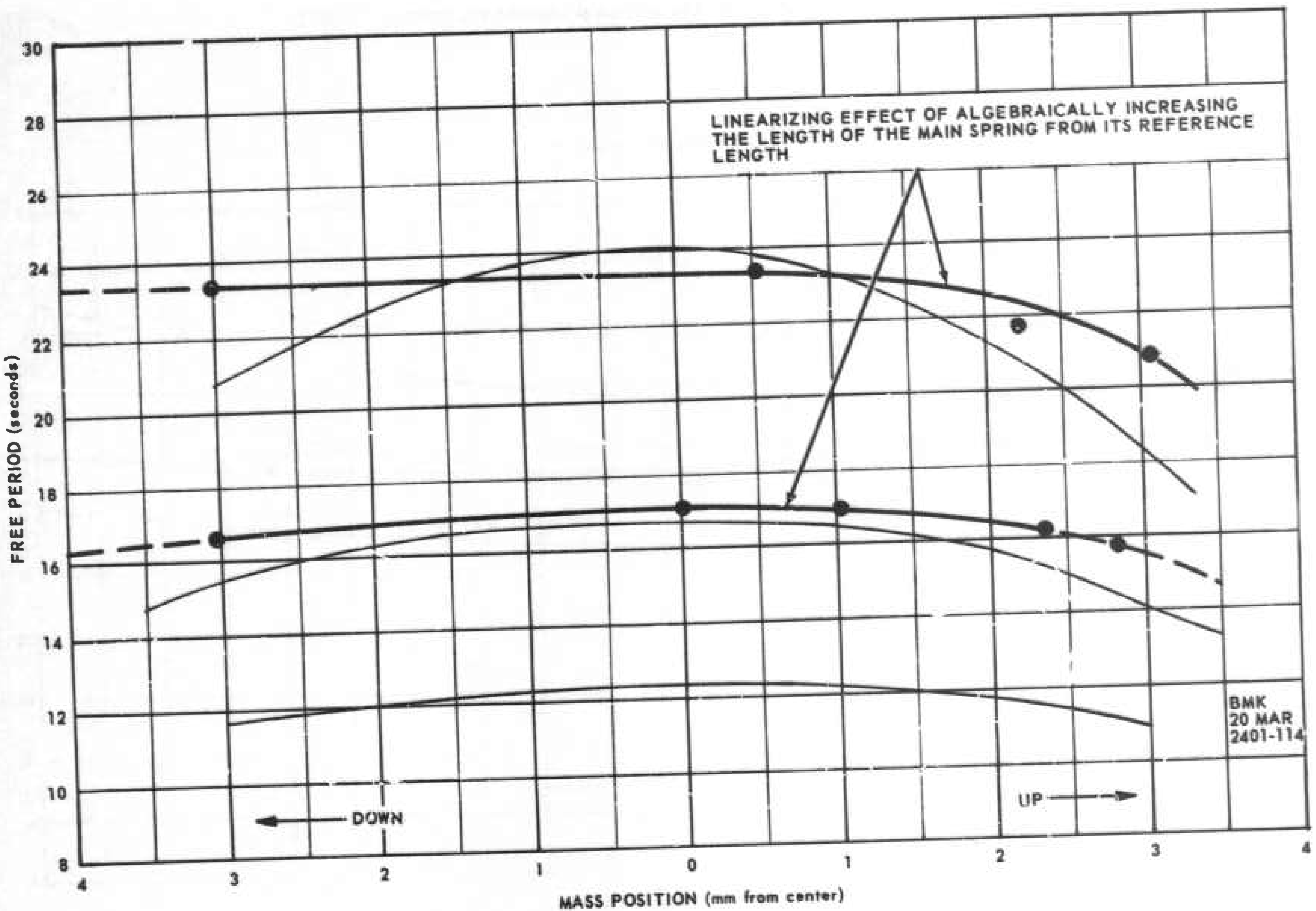

Figure 2. Free period as a function of mass position – Prototype, Model 26310 seismometer

G 2486

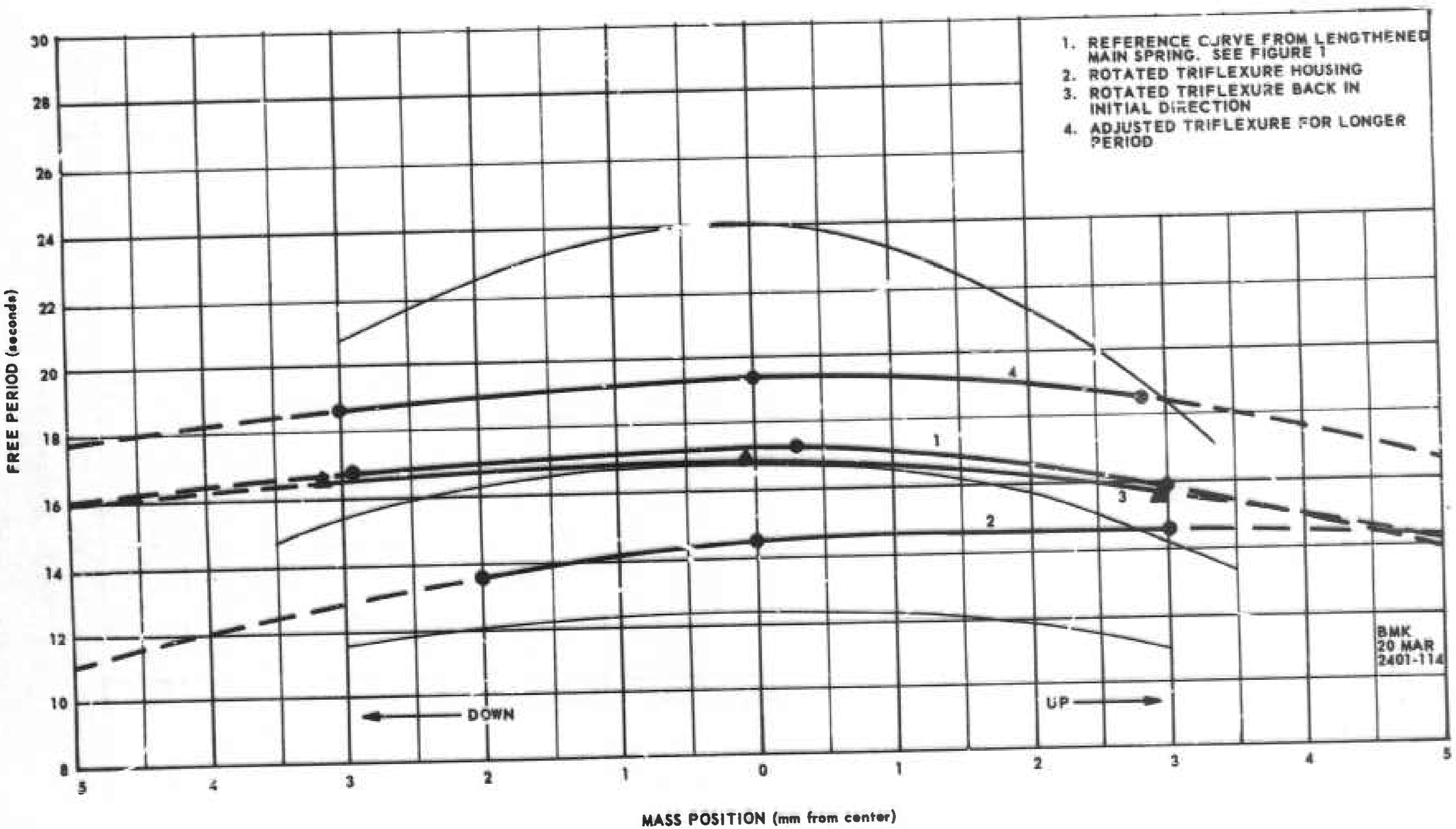

Figure 3. Free period as a function of mass position – Prototype, Model 26310 seismometer G 2487

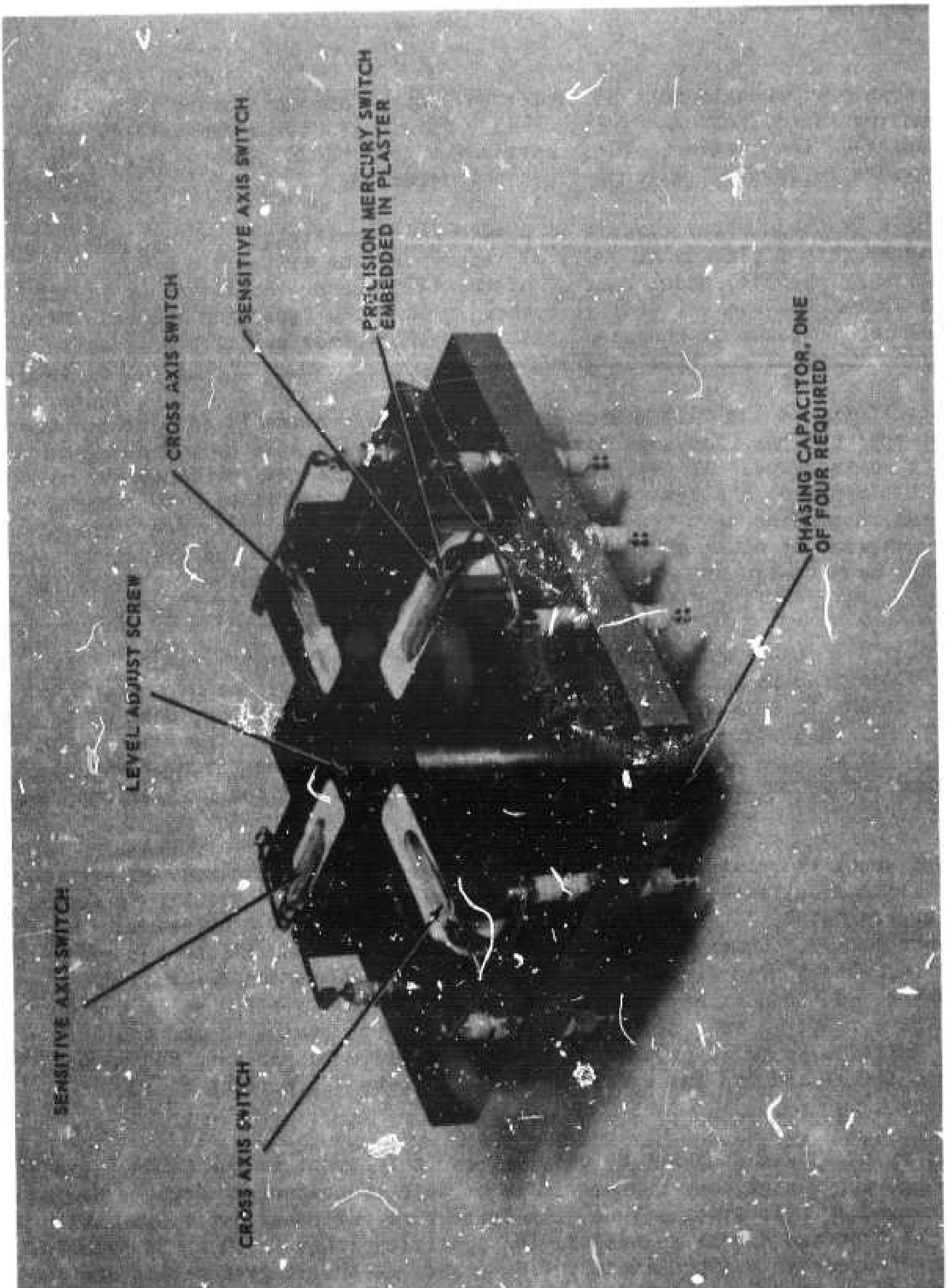

Figure 4. Tilt sensor, Model 26310 long-period borehole seismometer

G 2488

switches in a given axis must be prevented. Simultaneous closure is prevented by adjusting the tilt of the switches in a given axis for a sensitivity somewhat less than the maximum. This contributes to a "dead" zone or a zone in which errors in vertical alignment are not detected.

When the tilt-table motor circuit is electrically activated, and if the seismometer is not already at vertical reference, the tilt-table motors automatically operate, under control of the tilt sensor, until the sensitive element approaches the vertical reference in both the cross and the sensitive-axis planes. Because of the dead zone, the tilt sensor switches will open before the vertical position is reached.

The sensitivity of the tilt sensor in the cross-axis plane is adequate in the present application. The sensitivity in the sensitive axis is acceptable, but needs to be improved. At the present sensitivity, the mass is found at either the upper or the lower stop at the end of the sensitive-axis motor operation, depending upon the direction of the initial tilt; however, the mass can be centered by means of the auxiliary mass adjustment. The present auxiliary mass design and excursion is just sufficient to cover the error in mass position resulting from the dead zone of the sensitive axis sensor.

Errors in tilt resulting from the dead zone of the tilt sensor result in a shift in the free period as well as in mass position. Just as errors in the mass position are corrected by running the auxiliary mass motor, changes in the free period are corrected by running the period-adjust motor. Since the period adjustment is accomplished by changing the restoring force of the triflexure, further adjustment of the mass position after the initial one is not required.

Figure 5 shows the change in free period versus tilt for ±1 minute of arc (0.29 milliradian) from the reference position. The characteristic is seen to be approximately 7.6 seconds change per milliradian for a 20-second reference period. Comparing this characteristic with the tilt sensor sensitivity suggests that a free-period shift of 15.4 seconds could result from the sensor dead zone. Expressed as a percentage, the expected shift would be ±38.5 percent. A test at the 20-second reference period showed the actual shift to be ±31.2 percent. At shorter reference periods, the amount of the shift is reduced and was found by test to be 7.6 percent at 10.4 seconds.

A shift in free period caused by tilt errors is inherent in the LaCoste geometry. In the present design, our concern is to be able to compensate for the period shift caused by tilt error. Thus, the triflexure period-adjust range must cover the expected errors as well as the specified range of 10 to 25 seconds. The expected error is approximately 7.8 seconds at the longest period and 0.8 seconds at the shortest period. The present design covers the range from 8 through 35, or slightly in excess of that required.

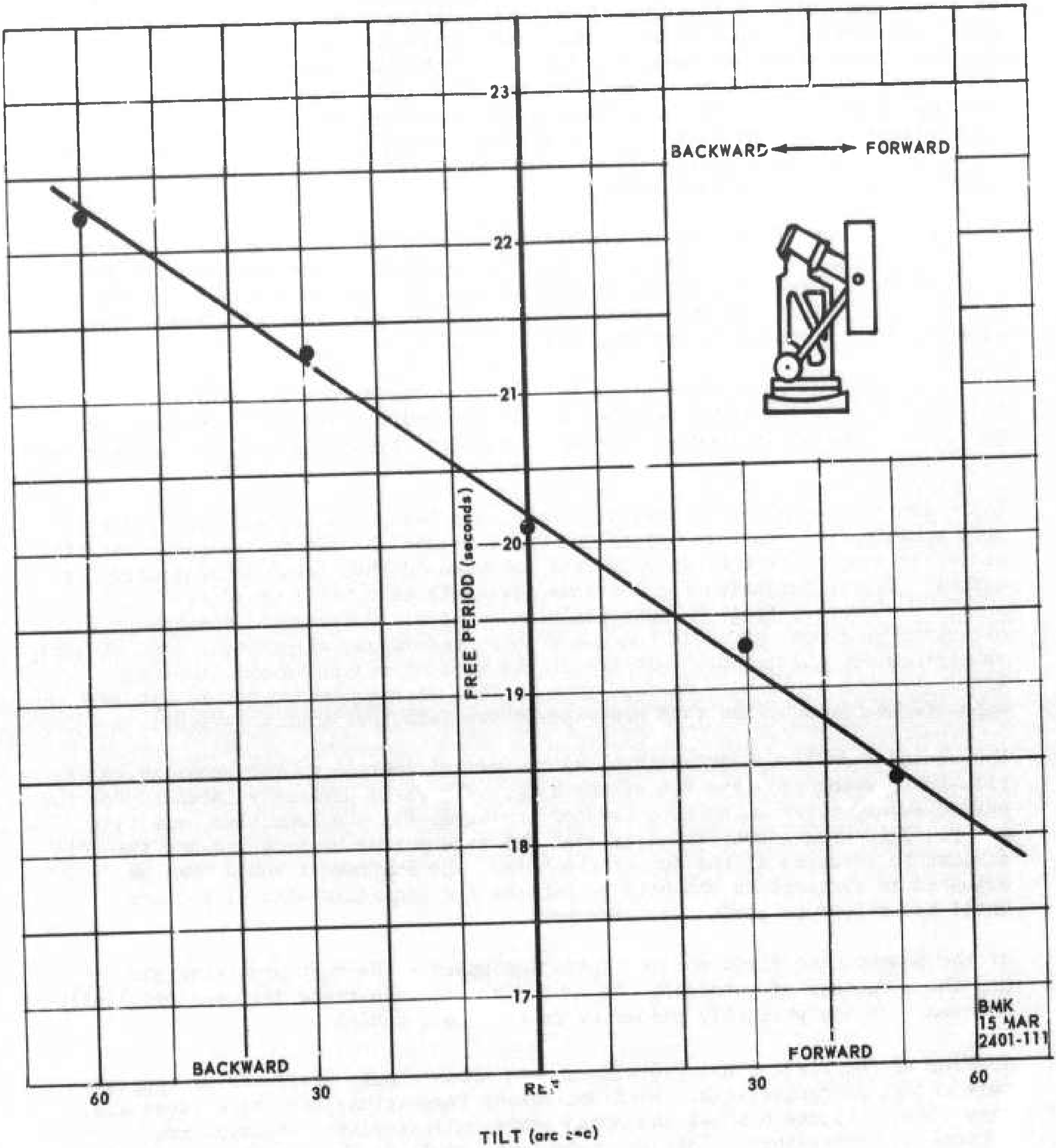

Figure 5 Free period as a function of tilt Prototype, Model 26310 seismometer G 2489

The need for improving the sensitivity of the sensitive axis sensor has lead to a re-examination of the mode of operation thus far assumed for the Model 26310 seismometer. This mode assumed that, following the unlocking sequence, the tilt table would automatically level in both the cross and sensitive axes. With sufficient precision of leveling, the mass could then be centered from the top of the hole by manually running the auxiliary mass motor in the direction indicated by the mass-position monitor. Further, the free period of the instrument could be adjusted through the range from the top of the hole by operating the period-adjust motor.

Remote operation of all the adjustable features of the seismometer is impractical due to the large number of conductors required in the uphole cable and the increased complexity of the instrument itself. But in the light of the marginal sensitivity of the sensitive axis sensor, some sort of a trade-off of adjustment features may be required.

At the moment, we know of no other level sensor having the simplicity and reliability of the mercury switches we are now using. There is, however, the choice of changing the mode of operation and thus bypassing the need for a more sensitive sensor.

There are two new modes of operation which are being considered. The first mode would operate much as before and would retain the cross-axis sensor as it presently exists. The cross-axis tilt table would thus level automatically as before. Tilt information for the sensitive-axis tilt table would be obtained, however, from the mass-position monitor. Output from the bridge circuit of the monitor would control a polarized relay, which would then directly substitute for the mercury switches of the present sensitive-axis sensor. Although there would be some dead zone in this arrangement as before, it is expected to be much less than was experienced with the mercury switches.

The second mode of operation involves the manual control of the sensitive-axis tilt-table motor from the top of the hole. The wires presently intended for the period-adjust motor would then be used, instead, for the sensitive-axis tilt motor. This arrangement requires that the free period be selected and the triflexure be adjusted at the top of the hole. The instrument would then be adjusted to vertical in the hole by running the sensitive-axis tilt motor until the reference period was observed.

At the moment, the first mode of operation appears the most promising and has the advantage of retaining all of the remote adjustment features originally assumed. We are presently preparing to test this scheme.

Testing of the first sensitive element has shown a mass drift versus temperature change characteristic. With decreasing temperature, the mass rises and vice versa. Figure 6 shows the approximate characteristic observed for decreasing temperature. This characteristic could be the result of tilt of the seismometer or a temperature characteristic of the suspension. Since we have confidence that the temperature compensation of the suspension was properly executed, a source of temperature dependent tilt was suspected.

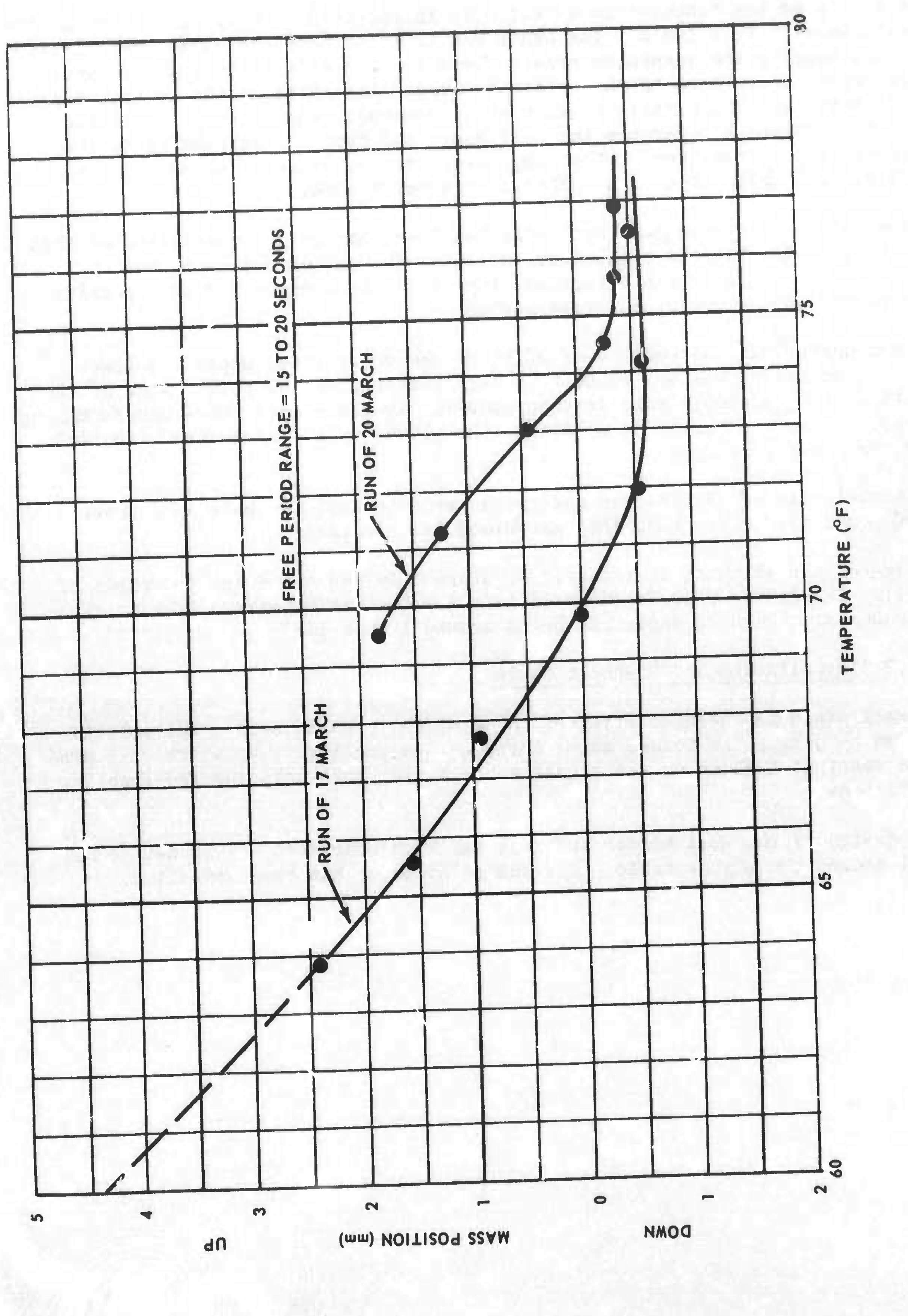

Figure 6. Typical mass drift as a function of temperature, initial tilt-table design

The source of the temperature sensitivity is believed to have been found in the sensitive-axis tilt table. The cause has at least been partially corroborated by zone heating the suspected area. There are two tilt table design features which could contribute to the drift observed. One involves the sensitive-axis drive motor and the manner in which it is mounted. The other involves the locking cams which reference the triflexure and thus the suspension to the tilt tables. Correction of the temperature compensation in these two areas involves only minor redesign. This is now being done.

Design of the period-adjust mechanism has been completed. Completion of this mechanism completes the seismometer design. This motor-driven mechanism controls the force on the adjustable lip of the triflexure and thus permits the remote adjustment of the free period.

A seismometer case assembly consisting of the outer case, upper and lower glands and seals, was subjected to a test pressure of 500 psig. None of the seals leaked, although some leakage occurred in the glands where manufacturing errors had been repaired by welding. The glands were subsequently reworked and are now satisfactory.

A short length of 13-3/8-inch casing was used to test the hole lock under a 1000-pound load. The hole lock performed satisfactorily.

Design of the shipping crates will be started during the first two weeks of April. The crates will be ready in time for the field tests of the triaxial seismometer, which we expect to begin around 1 June 1967.

2.2.2 Installation and Downhole Cable

A small winch has been constructed to spool the signal cable. The unit is driven by a constant torque motor through worm gearing. The winch will provide constant tension on the signal cable during both hoisting and lowering operations.

The design of the well header and seal has been completed. This device will seal around the signal cable after the seismometer has been installed.

APPENDIX to TECHNICAL REPORT NO. 67-16

STATEMENT OF WORK TO BE DONE

EXHIBIT "A"

STATEMENT OF WORK TO BE DONE

AFTAC Project Authorization No. VELA T/6706

1 - MAR 1966

1. Tasks:

a. Experimental Investigation of Thermal Noise. Continue the experimental investigation, defined in Project VT/072, of thermal noise components in seismograph systems, using torsional pendulums and associated equipment available from that project. Determine experimentally the spectral distributions of thermal noise in seismograph systems and compare the experimental results with theoretical predictions, as those derived by the National Bureau of Standards, for example. Provide data and methods for determining the ultimate possible magnification of a seismograph. Work on this task is to be completed within 4 months of the initial authorization date.

b. Development of a Long-Period Triaxial Borehole Seismometer. Modify the "Melton" long-period triaxial seismometer developed under Project VT/072 to adapt it for routine operation in shallow (200-foot) boreholes. Reduce the seismometer's diameter so it will fit inside standard 13.375-inch outside diameter shallow-well casing. Develop and add a suitable level sensor and remotely-controlled levelling device.

c. Preliminary Testing of the Long-Period Triaxial Borehole Seismometer. Prepare a cased, shallow borehole at a VELA seismological observatory to be designated by the AFTAC project officer. Assemble handling equipment for installing the seismometer. Conduct preliminary tests of the modified instrument in the test hole to determine its stability and the effects of temperature and local tilting as functions of depth. Through the use of improved installation techniques, selective filtering, design improvement or other means, develop a method for operating the seismometer so that magnification in the 10 to 100 sec period band is limited only by propagating seismic noise.

d. Field Measurements with the Long-Period Triaxial Borehole Seismometer. Collect and analyze data to determine long-period signal and noise characteristics in shallow boreholes, to identify principal long-period seismic noise components, to ascertain depth-environmental effects, and to compare the performance of the triaxial borehole seismometer with standard long-period seismometers.

2. Data Requirements: Provide report as specified by DD Form 1423, with Attachment 1 thereto.

AF 33(657)-16406

Attachment 1 to DD Form 1423
REPORTS
AFTAC Project Authorization No. VELA T/6706

1. General: Provide monthly, quarterly, final, and special reports in accordance with sentence 1, paragraph 1 of Data Item S-17-12.0, AFSCM 310-1; however, if that data item conflicts with the instructions of paragraph 2 below, the latter will take precedence.

2. Reports:

a. Monthly Status Reports. A monthly letter-type status report in 16 copies, summarizing work for the calendar month, will be submitted to AFTAC by the 5th day of the following month. Each report will be identified by the data listed in paragraph 2e and will include, but not be limited to, the following subject areas:

(1) Technical Status. Include accomplishments, problems encountered, future plans, actions required by the government, and appropriate illustrations and photographs.

(2) Financial Status. The contractor will follow the provisions of Data Item A-15-17.0, AFSCM 310-1A (Cost Planning and Appraisal Unit), in submitting financial data.

For the last month of each report period covered by a quarterly progress report, the monthly status report need include only the financial information.

b. Quarterly Progress Reports. Quarterly progress reports in 50 copies, summarizing work for 3-month periods, will be submitted to AFTAC within 15 days after the close of each such period. Each report will be identified by the data listed in paragraph 2e and will include the notices listed in paragraph 2f. Each report will present a precise and factual discussion of the technical findings and accomplishments for the entire report period, using a format similar to that of the final reports under Contract AF 33(657)-9967, as well as the technical information ordinarily required in the monthly reports.

c. Final Reports. The final report on Task 1a will be submitted in 50 copies to AFTAC within 60 days after work on that project is completed; the final report on the remaining tasks will be submitted in 50 copies within 60 days after the completion of all work. Each report will be identified by the data listed in paragraph 2e and will include the notices listed in paragraph 2f. Each report will present a complete and factual discussion of the technical findings and accomplishments of the project tasks, using the quarterly-report format.

d. Special Reports.

(1) Special reports of major events will be forwarded by telephone, telegraph, or separate letter as they occur and should be included in the

following monthly report. Specific items are to include, but are not restricted to program delays, program breakthroughs, and changes in funding requirements.

(2) Special technical reports may be required for instrument evaluations, project recommendations, and special studies when it is more desirable to have these items reported separately from the quarterly or final reports. Specific format, content, number of copies, and due dates will be furnished by this headquarters.

(3) All seismograms and operating logs, including pertinent information concerning time, date, type of instruments, magnification, etc., will be provided when requested by the AFTAC project officer.

e. Identification Data. All monthly, quarterly, and final reports will be identified by the following data:

AFTAC Project No. VELA T/6706.

Project Title.

ARPA Order No. 624.

ARPA Program Code No. 6F10.

Name of Contractor.

Contract Number.

Effective Date of Contract.

Amount of Contract.

Name and phone number of Project Manager, Scientist, or Engineer.

f. Notices.

(1) All quarterly and final reports will include the following notices on the cover and first page or title page:

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(2) All quarterly and final reports will include a copy of DD Form 1473, Document Control Data - R&D (Reference AFR 80-29). AFTAC will designate the appropriate Availability/Limitations Notice for use on these forms.

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3. REPORT TITLE

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c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
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13. ABSTRACT

The first module of a long-period triaxial borehole seismometer was assembled. Preliminary tests were conducted to determine its operating characteristics. An undesirable mass position versus temperature characteristic was observed. Probable causes have been determined and will be corrected.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Long-period borehole seismometer						
VT/6706						

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